HUMAN-LIKE CHARACTERISTICS for HIGH DEGREE of FREEDOM ROBOTIC DOOR-OPENING END-EFFECTOR

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ABSTRACT

In the field of military Unmanned Ground Vehicles (UGV's), military units are forced to sweep largely populated cities and towns in search of hostile enemies. These urban types of operations are referred to as MOUT (Military Operations on Urban Terrain). During urban operations, these UGV's encounter difficulties when opening doors. Current manipulator end effectors have these difficulties, because they are not designed to mimic human hand operations.

This paper explains the mechanical nature of the Modular Universal Door Opening End-effector (MUDOE). MUDOE is a result of our development research to improve robotic manipulators ability to negotiate closed doors. The presented solution has the ability to mimic human hand characteristics when opening doors. The end-effector possesses an ability to maintain a high Degree of Freedom (DoF), and grasp the doorknob by applying equally distributed forces to all points of contact.

Keywords: Manipulators, Door Opening, End-effector, Military Robotics

1. INTRODUCTION

Wars are no longer fought across open fields and through thick jungles. They are fought on urban terrain. While urban warfare is by no means a new phenomenon, with increased populations and the worldwide migration from rural to an urban society has put a stronger emphasis on Military Operations on Urban Terrain (MOUT)[1]. MOUT is complicated by challenging terrain, limited fields of view, ample cover for defenders and snipers, underground infrastructure, and the presence of civilians. To aid in these MOUT operations, military units utilize Unmanned Ground Vehicles (UGV's) to sweep the largely population cities and towns in search of hostile enemies, often by searching every building, house, and aboveground/underground structures.

During MOUT missions, UGV's often encounter closed and locked doors. Directing a robot with a claw-style end-effector to open a door is a time-consuming and strenuous task for robot operators. Most of the UGV platforms currently in use in the field are not well-suited to the task of opening doors, and, due to physical or mechanical limitations, some are not capable of opening doors at all. As illustrated in Figure 1, the most common style of end-effector used on the manipulator arms of UGVs is a claw. When opening a door, the claw pinches the doorknob with two to four points of contact, relying on the friction coefficient between the claw and the doorknob and the pinching force applied by the claw to secure and maintain a firm grip on the doorknob. This method is ineffective, as the claw tends to slip off the doorknob.

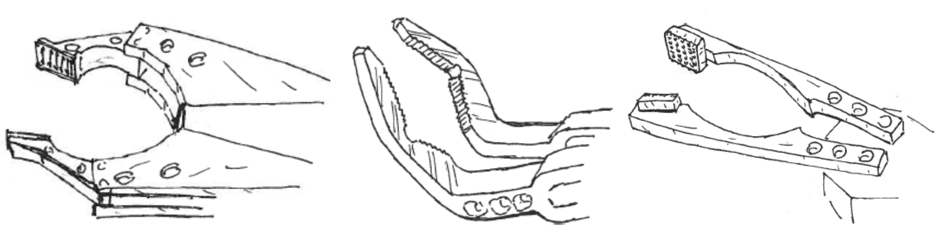

Figure 1. Examples of available manipulator end-effectors

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Doors, and, therefore, doorknobs, are designed for human users. For most people, opening a door is a familiar action that can be performed almost automatically. Little to no conscious thought is given to either the individual steps of grasping the doorknob, twisting the doorknob, and pushing or pulling the door open while maintaining a firm grip on the doorknob, or the hand, wrist, arm, and shoulder movements necessary to perform those actions.

Mechanically replicating the complex action encompassed by the command “open door” is a nontrivial endeavor. Military robotics must be inexpensive, robust, and effective. While it is possible to create a mechanical analogue of a human hand, such a device is not suitable for most military applications. Rather than mimic the form and function of a human hand, mimic the interaction between a human hand and a doorknob.

2. MODELING HUMAN-LIKE CHARACTERISTICS

Human hands possess a capability to grasp their object and conduct complex movements and rotations which are required to open the door. The process to open the door encompasses a grasping like motion that can maintain the positions of force and rotate the doorknob without interfering with its grasping hold on the doorknob. Functionally the human hand always applies an equally distributed force to all points of contact when the hand is closed and grasping an object. (See Figure 2)

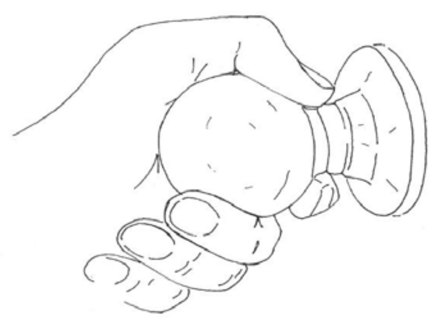

Figure 2. Hand grasping a round doorknob

Through multiple Degrees of Freedom (DoF), the human hand can also conduct this range of motion at a high degree of an off axis angle relative to the center axis of the doorknob (See Figure 3). Once the doorknob is rotated and the bolt is disengaged, the human pushes or pulls the doorknob, again using grasping hold and movements of the wrist, arm, and shoulder to maintain a firm grip on the doorknob as the door swings inwards or outwards. Most robotic actuated end effectors do not have the distinct capability to apply equally distributed forces to all points of contact, and maintain that distribution of force throughout the desired range of motion.

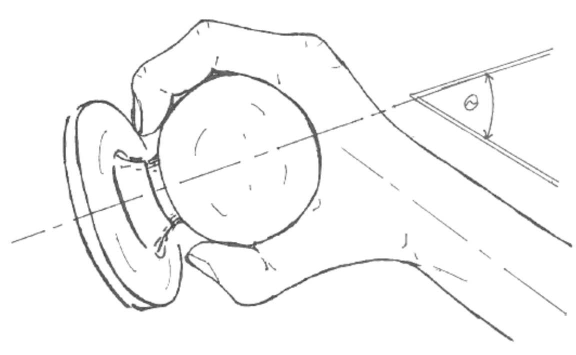

Figure 3. Human hand offset to doorknobs center axis

With a detailed understanding of the interaction between a human hand and a doorknob in mind, the mechanical equivalent may be extrapolated. Like a human hand grasping a doorknob, the end-effector must have multiple points of contact with the doorknob that apply equal forces to the doorknob, even if the end-effector is not perfectly aligned with the doorknob. Just as the hand, wrist, arm, and shoulder work in concert to open a door, the operation of opening a door robotically may be shared between the end-effector and the robotic arm to which it is mounted.

In order to achieve the equal distribution of force across multiple points of contact that may be misaligned, the Modular Universal Door Opening End-effector (MUDOE) employs the whiffletree concept of force distribution to conform its self to the doorknob/handle. As illustrated in Figure 4, the Whiffletree mechanism distributes force evenly through a series of linkages that pivot at or near the center of the applied force. Each of the loads (Load 1, 2, and 3) are balanced from each side of the load, preventing the load from tugging alternately on each side. The Whiffletree can be used in both tension and compression. Common applications of the whiffletree mechanism include the harnesses of draught animals, such as horses pulling plows, and windshield wipers.

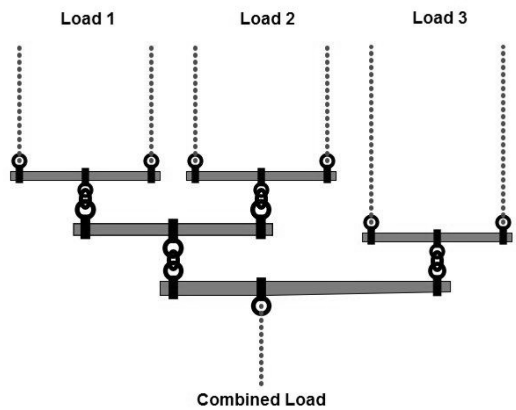

Figure 4. Whiffletree load distribution concept[2]

In the case of the MUDOE, the whiffletree concept of force distribution is used in compression. Instead of multiple loads under tension resulting in one combined pulled tension force, a single force is applied and is distributes it evenly to its appendages (See Figure 5). Ball joint swivel bearings and pins are used as pivot points between the linkages. This underlying design allows the MUDOE to utilize a single actuator to apply equally distributed forces to each of the four finger-like appendages, while maintaining multiple DoF.

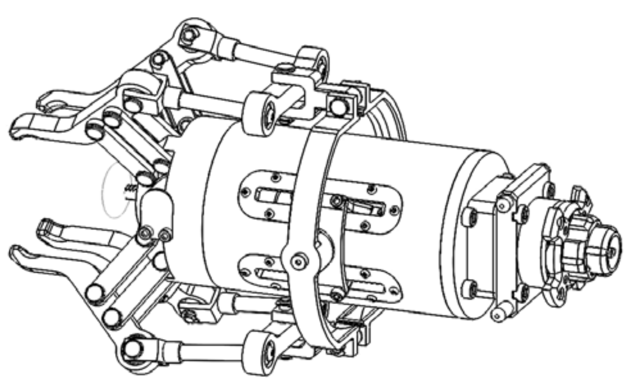

Figure 5. MUDOE dimetric drawing

MUDOE interfaces with a manipulator arm that provides tool rotation, Electrical Power Take-Off (EPTO), interface communication, and Mechanical Power Take-Off (MTPO). The MPTO provides the linear motion to the first set of three linkages, which is an outer collar. The outer collar creates a pivot between the second set of linkages, the top and bottom sets of finger-like appendages of the end-effector. The second set of linkages, mirrored on the top and bottom of the outer collar, act as pivots between the left and right fingers on the top and bottom of the end-effector. The third set of linkages connects each finger to one side of either the top or bottom cross-bar. Figures 6 and 7, respectively, illustrate the open and closed positions of the fingers of the end-effector without a resistive load. The pinned pivots are spring-loaded to maintain their unloaded alignments (As represented in Figure 5). If equal forces are applied to all four fingers, each linkage bar maintains position and forces each finger to simultaneously close.

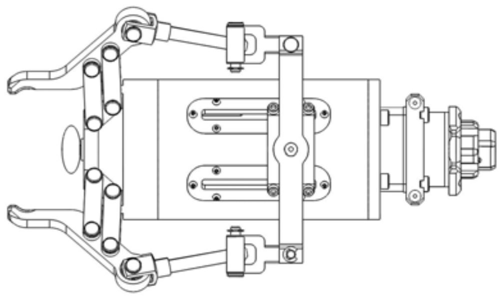

Figure 6. MUDOE side view, open position

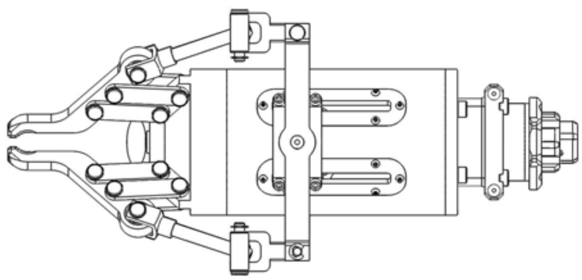

Figure 7. MUDOE side view, closed position

When the fingers encounter uneven resistance, such as when grasping a doorknob without precisely aligning the central axis of the doorknob and end-effector, the applied force is distributed through the linkage system and the fingers adjust their relative positions accordingly. Figure 8 illustrates the first linkage, the outer collar, rotating to compensate for a greater force applied to the top two fingers of the end-effector. The bottom fingers are rotated forward until the forces are evenly distributed. Figure 9 illustrates the second linkage, the cross bar, rotating to compensate for a greater force applied to the two right fingers of the end-effector. Again, the opposing fingers are rotated forward until the forces are evenly distributed. Both of these cases allows MUDOE to conform to the object off axis regardless of position, and it then can maintain constant force and conformity while the MUDOE tool is being rotated by the manipulator’s arm to generate the “opening” feature required for doorknobs. This feature also allows the end-effector to encompass movements that are normally conducted by a human hand and wrist capabilities into the grasping connection to the doorknob.

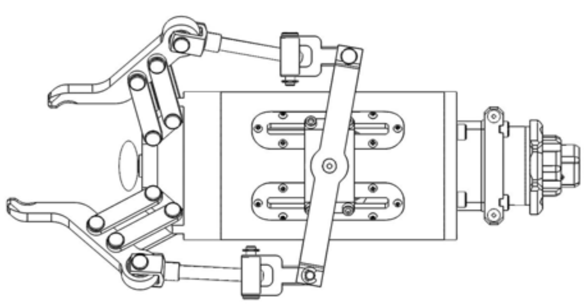

Figure 8. Resistive force applied to the top fingers, rotating the outer collar (first linkage bar)

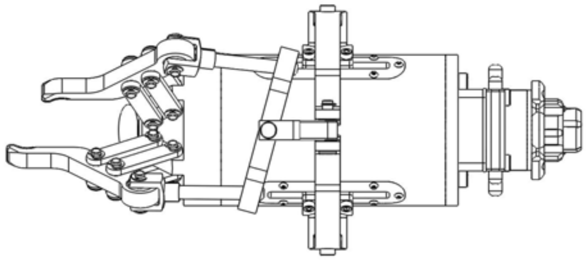

Figure 9. Resistive force applied to the right fingers, rotating the cross-bar (second set of linkage bars)

Unlike a human hand using its four fingers and opposable thumb to produce the grasping force into the center of the palm, MUDOE contains an extendable center appendage to mimic this behavior. The center palm reactionary force and the four fingers generate five points of contact that create a grasping motion that is similar to a human hand. The combination of a material with a high coefficient of friction applied to the fingers, and the angled ends of the fingers prevents the palm from pushing the doorknob out of the end-effector's grasp. Once the doorknob has been turned, the palm may also apply the pushing force necessary to open inward-swinging doors without the fingers losing their grip on the doorknob. Figure 10 illustrates the five forces vectors applied to the center point of gravity for the doorknob by the end-effector's fingers and palm. Comparing Figure 2 to Figure 10, it is clear that the MUDOE is an accurate mechanical analogue of the interaction between a human hand and a doorknob.

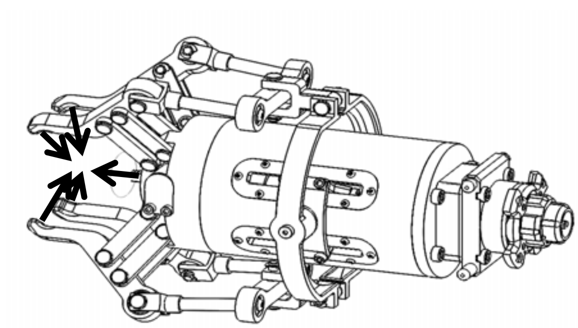

Figure 10. MUDOE Diametric View – Applied Force Vectors

3. MODULARITY AND VERSATILITY

As the word 'modular' in the project's name suggests, the MUDOE was designed to have the capability to be exchanged for others end-effectors on its operating manipulator arm. As a result, the robotic manipulator arm platform can operate multiple specialized end-effectors to best perform its duties. The MUDOE has been integrated to work with a commercially available inter-change robotic manipulator arm.

The inter-change manipulator provides UGV platforms with the ability to automatically change end-effectors while down range to achieve multiple mission capabilities and reduce overall mission time. As shown in Figure 11, the manipulator is a low-cost modular robotic arm with a magazine of end-effectors. An operator is able to load end-effectors that are best suited for the mission at hand. Among the eight currently available end-effectors an operator may choose from, some of which are shown in Figure 12, MUDOE is designed to be a modular universal door opening solution. Although the MUDOE's current design reflects the platform for which it was designed, the conceptual design and the capabilities of the end-effector can be fitted to other platforms.

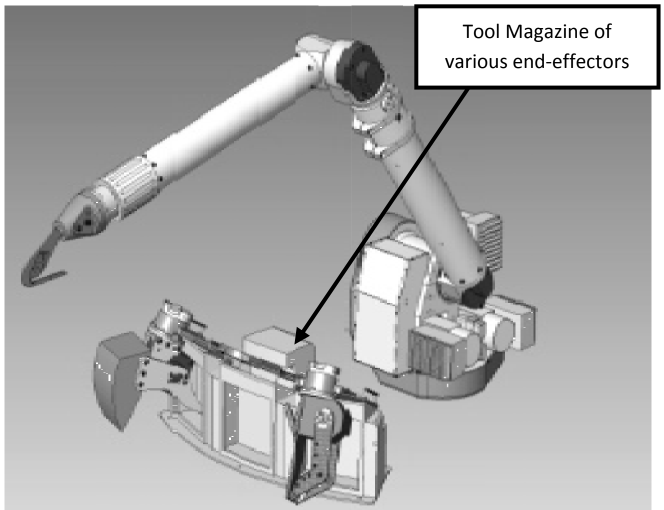

Figure 11. Modularity of the inter-change manipulator arm

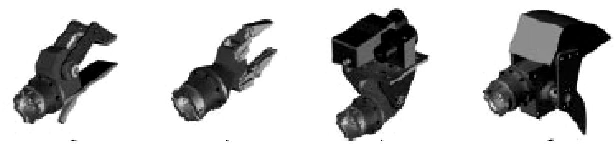

Figure 12. Examples of additional end-effectors available for tool inter-change

MUDOE is designed to negotiate the residential and commercial doorknobs found throughout the world. In addition to its intended function as a universal door opener, the MUDOE may be utilized to fulfill other mission objectives as well, overcoming the functionality limitation of claw-style grippers.

4. AFFORDABILITY

Robotic manipulators vastly range in cost due to their complexity. Robotic engineers focus not only on the functionality, but the cost, reliability, and manufacturability. The benefit from the MUDOE design and utilizing the whiffletree concept is the reduction is the number of actuators required to do the behavioral moves while maintaining a high DoF. MUDOE consist of only one actuator which controls the center of the palm. All other remaining movements are provided by the manipulator arm's rotation and MPTO. The ability to reduce the number of actuators generating the degrees of freedom results in a large reduction in cost. MUDOE also was designed to maximize the number of low-cost and easily available COTS components to be integrated into the end-effector. Specialized or low volume COTS items can also negatively affect the end-effectors overall cost. Another factor that becomes a concern is the software development required to operate the device. The end-effector communicates with the manipulator via CAN bus. The Printed Circuit Board (PCB) within MUDOE contains the necessary control software to communicate with the arm over this CAN bus. MUDOE is ultimately controlled from an Operator Control Unit (OCU). The control/feedback messages between the OCU and the manipulator arm are based on the Joint Architecture for Unmanned Systems (JAUS) standard. JAUS is an open architecture that enables interoperability.

Future work will be concentrated on environmental hardening of the MUDOE tool. After prototype testing and Warfighter user assessment has been completed, the design engineers will address any design issues, if necessary, and then turn their focus towards hardening and weather proofing so it is suitable for Warfighter use in the field. Additional future work may include lock-picking or locked door denial, opening car doors, and push-button door handles

5. FIGURES AND TABLES

Although the MUDOE only begins to utilize the Whiffletree concept once forces are applied to the fingers, Figure 13 illustrates MUDOE's ability to negotiate a doorknob off the center axis while the doorknob is separated from its grasp. The MUDOE can still conform to the doorknob as if the center axes were aligned.

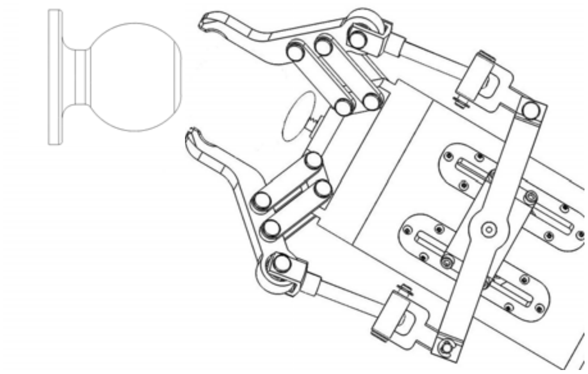

Figure 13. MUDOE ability to negotiate doorknob off axis

6. CONCLUSION

The Modular Universal Door Opening End-effector represents a novel approach to a practical problem. Rather than imitating a complex mechanical system, the MUDOE imitates the interaction between the complex mechanical system and its target, reducing the number of actuators necessary to perform the action while maintaining the appropriate number of degrees of freedom. By maximizing the use of commercial off-the-shelf (COTS) components, the design is further simplified. The MUDOE is an inexpensive, robust, and effective solution to a demonstrated need of the modern, UGV-leveraging Warfighter. Future work has also been formulated.

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